



Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

Cosme, Nuno Miguel Dias; Larsen, Henrik Fred; Hauschild, Michael Zwicky

Publication date:
2013

[Link back to DTU Orbit](#)

Citation (APA):

Cosme, N. M. D. (Author), Larsen, H. F. (Author), & Hauschild, M. Z. (Author). (2013). Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures. Sound/Visual production (digital) <http://www.york.ac.uk/conferences/allatsea/index.html>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.



Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures



*Session: Nutrients and ecology of the coastal zone and how they improve our understanding of environmental change
Thu July 4th 2013 – University of York*

Nuno Cosme, Henrik F. Larsen, Michael Z. Hauschild

nmdc@dtu.dk

Research Assistant and PhD student



Technical University of Denmark

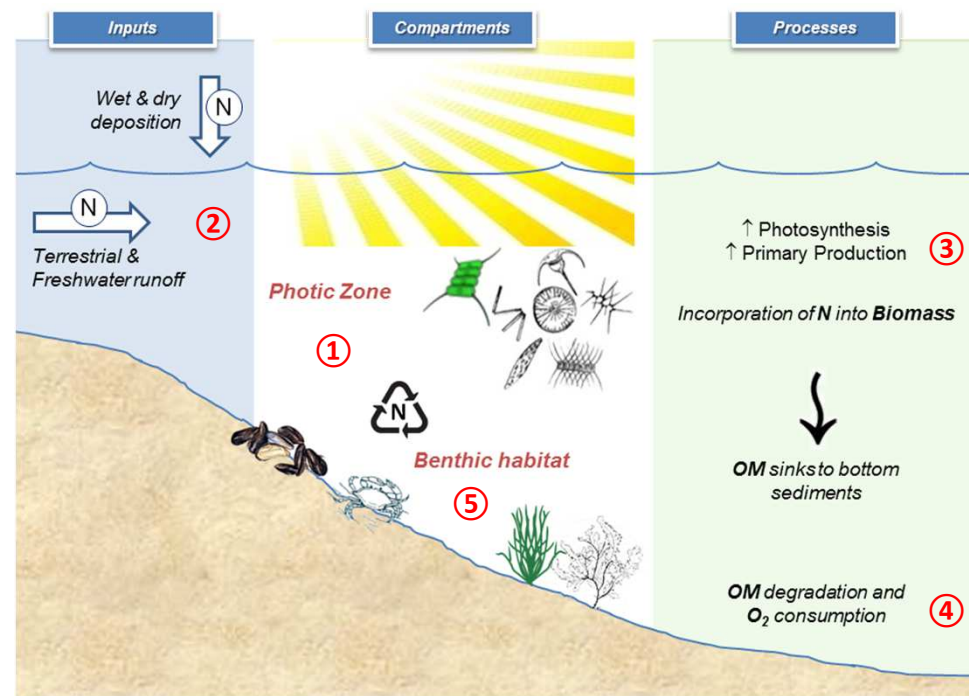


This research was partly financed by the EU LC-IMPACT project: Development and application of environmental Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies (Grant agreement No.: 243827 – LC-IMPACT), which is financially supported by the EU Commission within the Seventh Framework Programme Environment ENV.2009.3.3.2.1: Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies.

Marine Eutrophication

Ecosystem response to the availability of plant nutrients

- ① PP sustained by **nutrients** released from microbial and animal metabolism.
- ② **Balance disrupted** by anthropogenic fertilization.
Sources: run-off from agriculture, atmospheric deposition, and sewage waters.
- ③ Nutrients enrichment promotes **excessive growth** of phytoplankton and macroalgae.
- ④ Bacterial degradation of biomass **consumes dissolved oxygen**. Excessive oxygen depletion may originate hypoxic to anoxic bottom waters.
- ⑤ Sublethal and lethal **effects** on resident biota are expected.



Life Cycle Assessment

LCA and LCIA

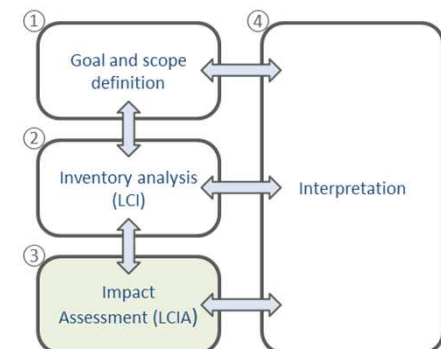


Life Cycle Assessment (LCA)

- Environmental assessment tool
- Evaluates the environmental exchanges (technosphere-ecosphere)
- Potential environmental impacts of a product or service throughout the entire life cycle (resources extraction, processing, manufacturing, assembly, packaging, transport, use, reuse, recycling, and disposal stages)

Life Cycle Impact Assessment (LCIA)

- Characterisation of emissions with Characterisation Factors (CF)
- CFs are substance-specific and represent the substance potency
- CFs translate emissions into potential impacts
- Regional and global impacts



Future scenarios

Increase in food demand

Climatic-driven pressures

Increase in crops productivity



- More impacts
- New locations
- Management
- Legislation/regulations
- Best practices
- Guidelines

Projected development of cereal production, global population, fertilizer use and arable land (FAO 2003)



Drivers and goals

Research question

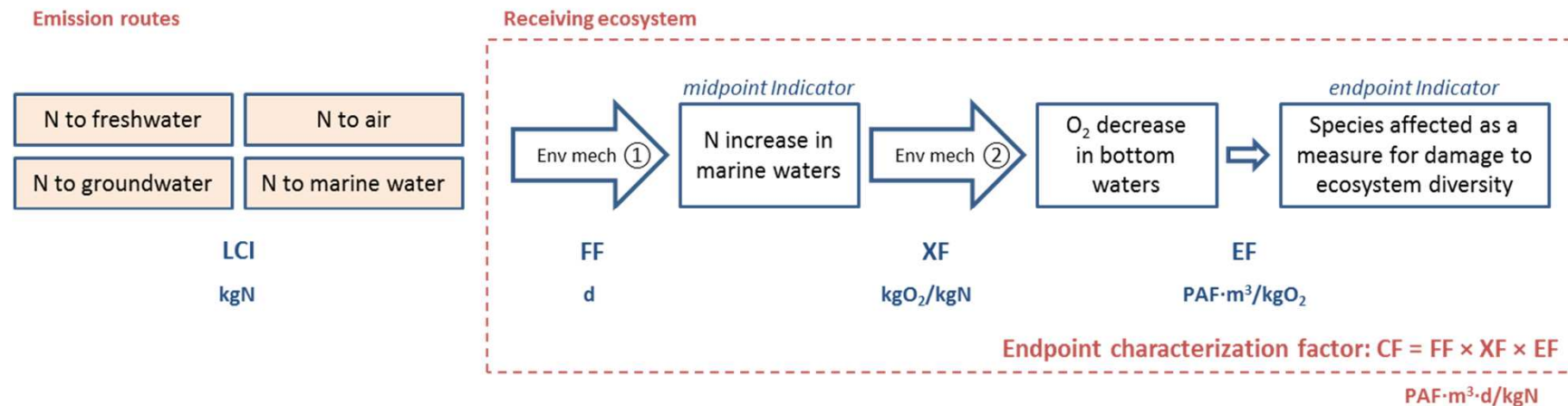
- Understand the **fate processes** affecting nitrogen loadings to coastal waters
- Include ecosystems' sensitivity to obtain a damage dimension (loss of biodiversity)
- Estimate factors for the impact characterisation (**CFs**)
- Introducing **spatial differentiation** at a suitable scale
- Produce an endpoint damage model to support decision-making processes



How to define CFs for marine eutrophication in a spatially differentiated LCIA endpoint model?

Model framework

From environmental mechanisms to factors



To define the **Characterisation Factor (CF)** in (PAF·)[m³·d/kg]:
$$CF_{ij} = FF_{ij} \cdot XF_j \cdot EF_j$$

Where:

- FF_{ij} is the **Fate Factor** [d] for emission route i to receiving ecosystem j
- XF_j is the **Exposure Factor** [kgO₂/kgN] in receiving ecosystem j
- EF_j is the **Effect Factor** (PAF·)[m³/kgO₂] in receiving ecosystem j



Fate Factor

The FF_{ij} [d] is obtained by:

$$FF_{ij} = \frac{f_{exp\ i}}{\lambda_j}$$

Where:

- $f_{exp\ i}$ [dimensionless] is the fraction of the emitted N that reaches coastal marine waters (exported) calculated for each emission route i
- λ_j [d⁻¹] is the N-loss rate coefficient in receiving ecosystem j

$f_{exp\ i}$ ***River-N fate***

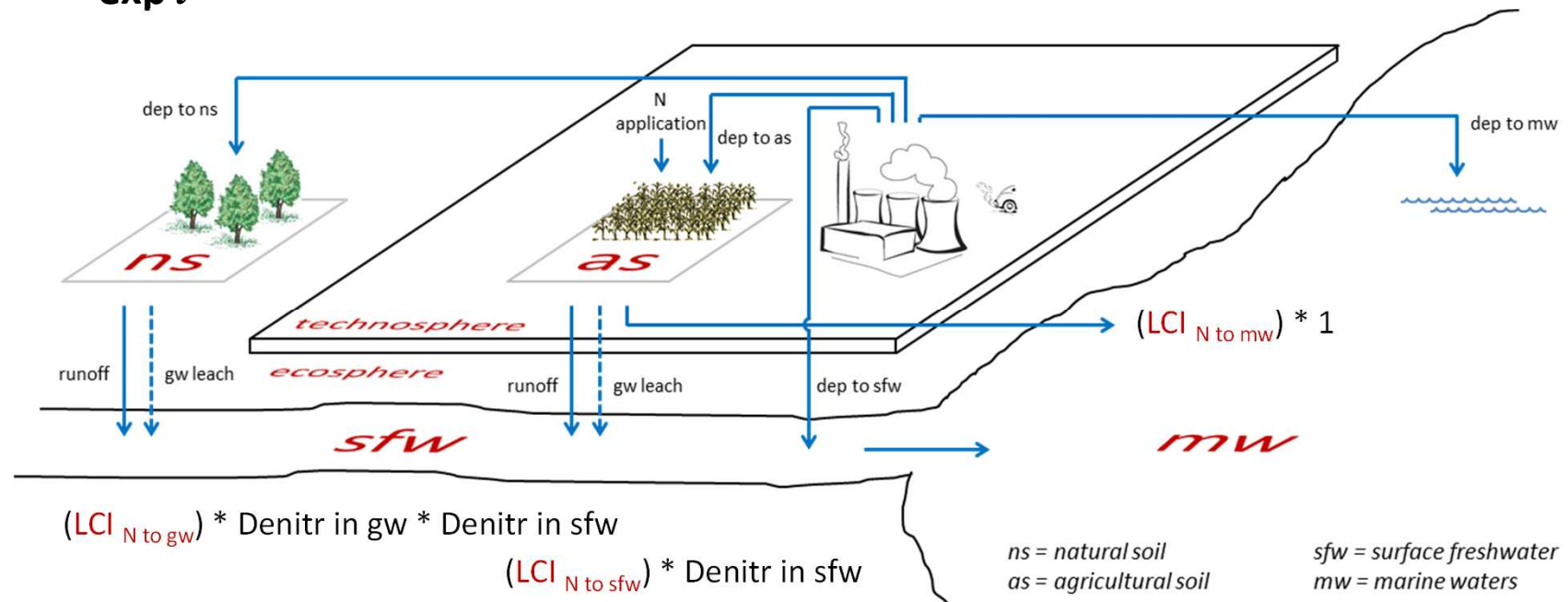
λ_j ***Marine-N fate***

River-N fate modelling

Fate modelling and export to marine coastal waters

$$f_{exp i} =$$

$$\begin{aligned} & (LCI_{N \text{ to air}}) * f_{dep \text{ to sea}} * f_{dep \text{ to mw}} + \\ & (LCI_{N \text{ to air}}) * f_{\text{to inland}} * f_{dep \text{ to ns}} * f_{leach \text{ from ns}} * \text{Denitr in sfw} + \\ & (LCI_{N \text{ to air}}) * f_{\text{to inland}} * f_{dep \text{ to as}} * f_{leach \text{ from as}} * \text{Denitr in sfw} + \\ & (LCI_{N \text{ to air}}) * f_{\text{to inland}} * f_{dep \text{ to sfs}} * \text{Denitr in sfw} \end{aligned}$$





Marine-N fate modelling

Nitrogen losses (λ_j) in the marine compartment may be caused by:

- Denitrification $\approx 30\%$ (Van Drecht et al., 2003)
(microbial mediated reduction of NO_3^- , NO_2^- and NO into N_2 in bottom sediments)
- Sedimentation $\approx 5\%$ (Nixon et al., 1996)
(loss to mineralization of N into bottom sediments)
- Advection $\approx 1/\tau$
(transport of nitrogen forms or net flushing)

To find residence time (τ):

- Search literature
 - Build archetypes:
- High dynamics & exposure to regional currents: $\tau \approx 3 \text{ mo}$
 - Medium dynamics & exposure to local currents: $\tau \approx 2 \text{ yr}$
 - Low dynamics: $\tau \approx 25 \text{ yr}$
 - Very low dynamics or embayment: $\tau \approx 90 \text{ yr}$



Marine-N loss rate coefficient (λ_j)

Includes the 3 loss routes:

- Denitrification
- Advection
- Sedimentation

$$\lambda_j = \lambda_{denitr} + \frac{1}{\tau_j} + \lambda_{sed}$$

N-loss routes follow first-order kinetics with a constant removal rate (λ_r)

$$N_t = N_0 \cdot e^{-\lambda_r t}$$

$$\lambda_{denitr} = -\ln(0.70)$$

$$\lambda_{sed} = -\ln(0.95)$$

From literature or archetypes to find τ_j for LME j

$$\lambda_{adv} = \frac{1}{\tau_j}$$



Exposure Factor (XF)

The XF_j (unit: kgO_2/kgN) is estimated by:

$$XF_j = \frac{\text{kgOM}}{\text{kgN}} \times \frac{\text{kgO}_2 \times (1 - \text{BGE})}{\text{kgOM}} \times \text{NIE}_j$$

after

(photosynthesis)

after ()

(respiration)

(del Giorgio & Cole, 1998) then: ()

Bacterial Growth Efficiency is the amount of new bacterial biomass produced per unit organic C substrate assimilated

with

(Nixon et al., 1996)

Nitrogen Incorporation Efficiency expresses the environmental factors affecting PP rates (ecosystem response)

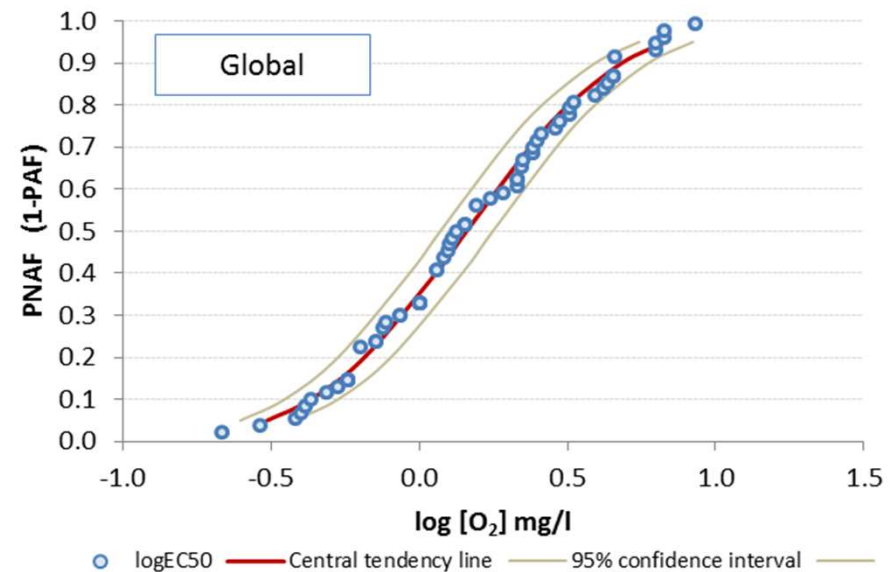
Effect Factor (EF)

The EF_j (unit: $PAF \cdot m^3/kgO_2$) is estimated by the average gradient method (Pennington et al., 2004):

$$EF = \frac{\Delta PAF}{\Delta [O_2]} = \frac{0.5}{HC_{50}}$$

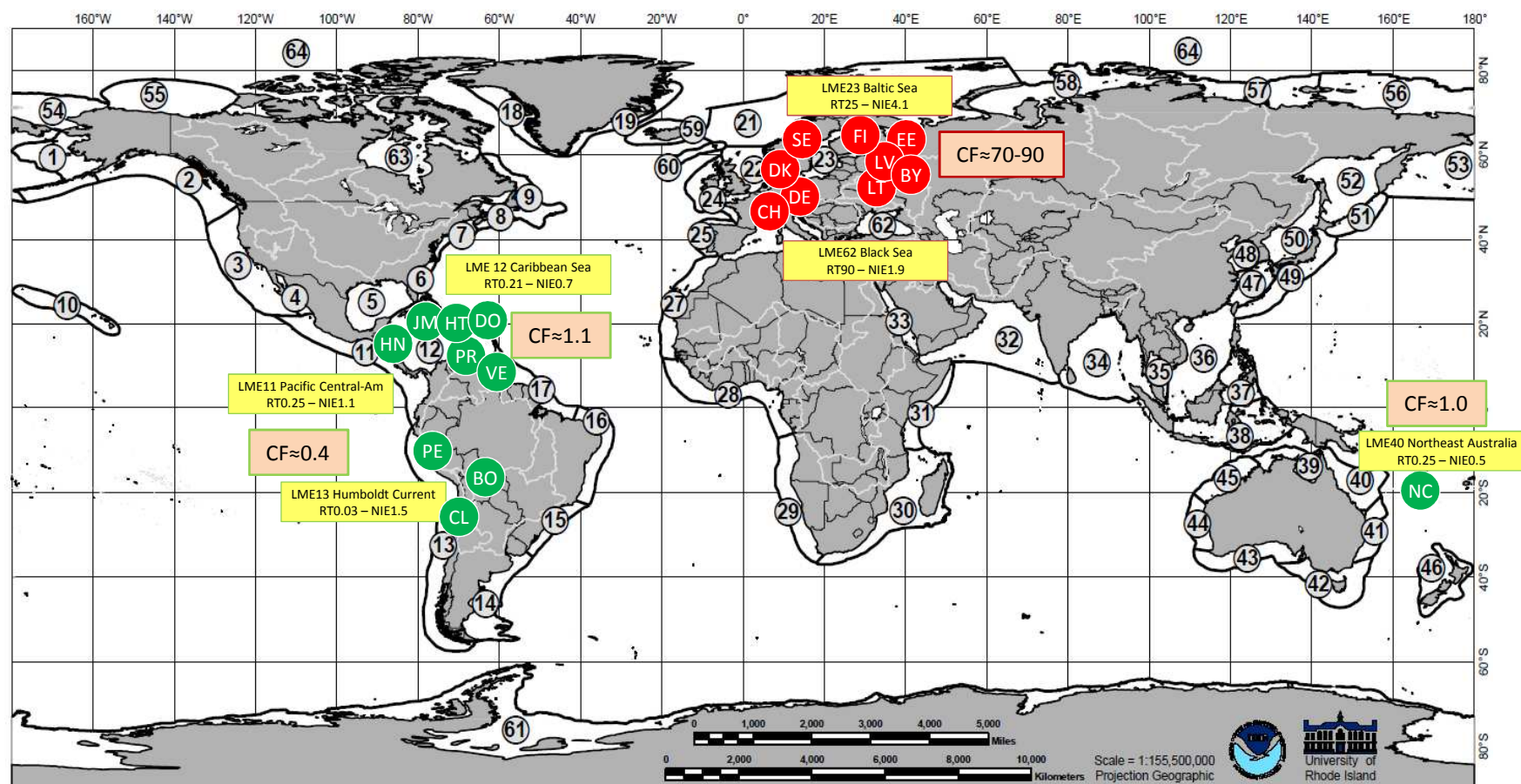
where $HC_{50} = 10^{avg(log EC_{50})}$
Species sensitivity to hypoxia (EC_{50})
from Vaquer-Sunyer & Duarte (2008)

- The Potentially Affected Fraction of species (PAF) is a measure of the loss of biodiversity in the receiving ecosystem
- From Species Sensitivity Distribution (SSD) curves for 5 climate zones + global
- Probabilistic model that estimates the variability of the sensitivity of individual species to an environmental stressor (Posthuma et al. 2002)



Spatial differentiation of the model results

Geographical distribution of the countries showing the Top10 (red) and Bottom10 (green) CFs (emissions to surface freshwater). **CF unit = $\times 10^3$ PAF·m³·d/kgN**



Sensitivity analysis

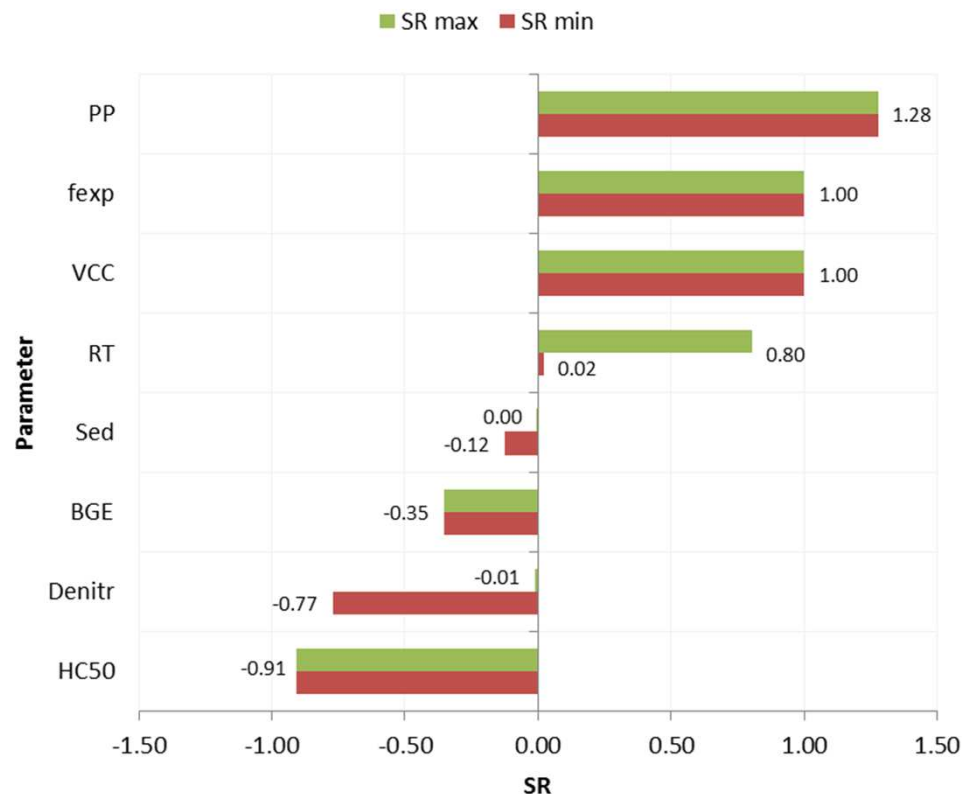
Sensitivity Ratios (SR) were calculated by:

$$SR_X = \frac{(CF_{end} - CF_{start}) / CF_{start}}{(X_{end} - X_{start}) / X_{start}} \quad (\text{Strandesen et al., 2007})$$

Tested input parameters:

- f_{exp} in *FF*
- Sedimentation rate in *FF*
- Denitrification rate in *FF*
- Residence time (LME) in *FF*
- BGE in *XF*
- PP rate in *XF*
- VCC in *XF*
- HC_{50} value in *EF*

Independent 10% variation of each input parameter





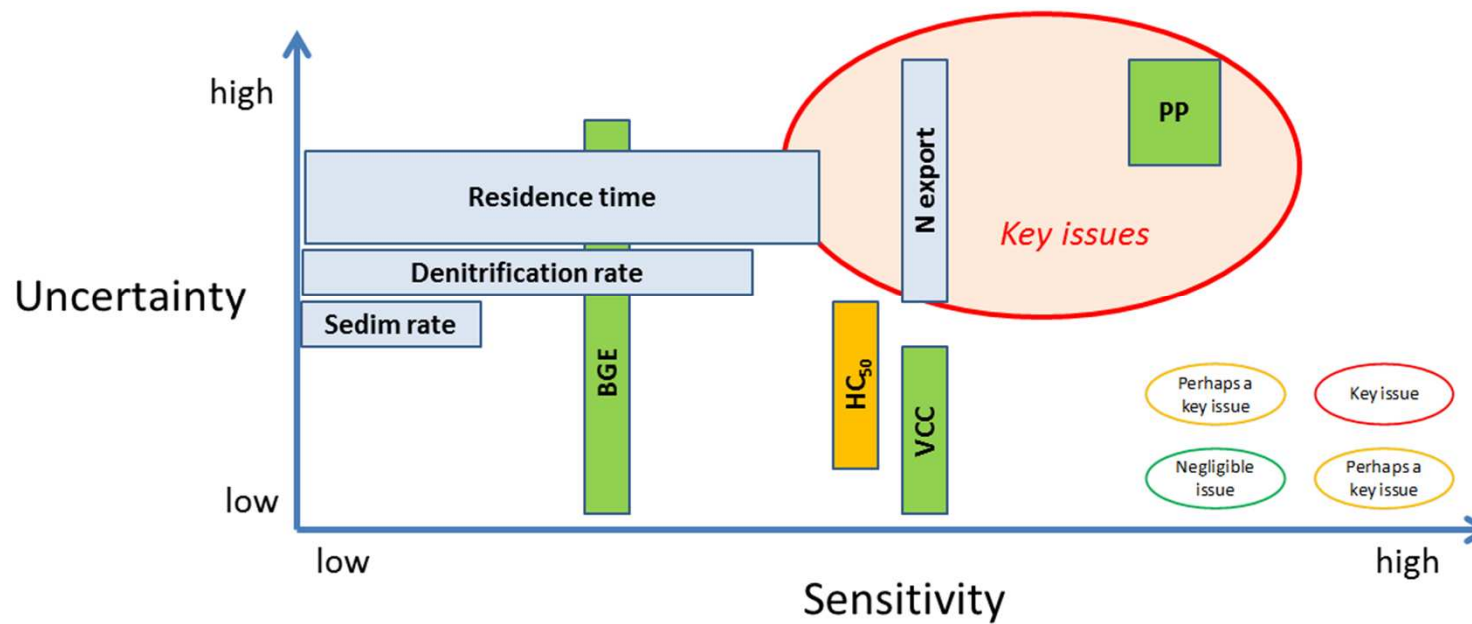
Uncertainty estimation

Extreme values of possible variation range

- f_{exp} for countries exporting to multiple receiving LME: **null to total export**
- Sedimentation rate: **5% to 8%** (Nixon et al., 1996)
- Denitrification rate: **30% to 52.7%** (Van Drecht et al., 2003 and Wollheim et al., 2008)
- Residence time: **lower to upper archetype or -50%/+50% of used value**
- BGE: **0.01 to 0.69** (del Giorgio & Cole, 1998)
- PP rates datasets show discrepancies between different sources: **high uncertainty**
- VCC is a model decision: **low uncertainty**

Key issues

Combining sensitivity and uncertainty





Weaknesses

- Dependency on third-party models (emissions, deposition)
- Dependency on the LCI model for the spatial aggregation of CF and NFs
- Unknown uncertainty associated with these ‘input’ models
- Low confidence on PP dataset
- No spatial differentiation for marine sedimentation and denitrification rates in the FF



Strengths

- Endpoint modelling
- Transparent and reproducible FFs, XFs, and EFs
- Spatially differentiated CFs
- High geographic applicability
- CFs and NFs for 233 Country-to-LME and 143 countries for 4 N-emission routes
- Global default CF and NF
- Key issues for data quality improvement identified

Thank you for your attention

References:

- del Giorgio PA, Cole JJ. 1998. Bacterial growth efficiency in natural aquatic ecosystems. *Annu. Rev. Ecol. Syst.* 29: 503-541.
- FAO. 2003. *World Agriculture: Towards 2015/2030 - An FAO Perspective*. Earthscan Publications, London, UK.
- Nixon SW, Ammerman JW, Atkinson LP, et al. 1996. The fate of nitrogen and phosphorous at the land-sea margin of the North Atlantic Ocean. *Biogeochemistry* 35: 141-180.
- Pennington DW, Payet J, Hauschild M. 1994. Aquatic ecotoxicological indicators in life-cycle assessment. *Environmental Toxicology and Chemistry* 23(7): 1796-1807.
- Posthuma L, Suter II GW, Traas TP (eds.). 2002. *Species Sensitivity Distributions in Ecotoxicology*. Boca Raton FL: Lewis Publishers.
- Van Drecht G, Bouwman AF, Knoop JM, Beusen AHW, Meinardi CR. 2003. Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater, and surface water. *Global Biogeochemical Cycles* 17(4), 1115.
- Vaquier-Sunyer R, Duarte CM. 2008. Thresholds of hypoxia for marine biodiversity. *PNAS USA* 105: 15452-57.
- Wollheim WM, Vörösmarty CJ, Bouwman AF, Green P, Harrison J, Linder E, Peterson BJ, Seitzinger SP, Syvitski JPM. 2008. Global N removal by freshwater aquatic systems using a spatially distributed, within-basin approach, *Global Biogeochemical Cycles*, 22, GB2026.

Technical University of Denmark



DTU Management Engineering
Department of Management Engineering

